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### Geology of a Mineralized Breccia "Pipe" near Basin, Montana

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GEOLOGY OF A MINERALIZED BRECCIA "PIPE"  
NEAR  
BASIN, MONTANA

by  
James W. Allan

A Thesis

Submitted to the Department of Geology  
in Partial Fulfillment of the  
Requirements for the Degree of  
Bachelor of Science in Geological Engineering

MONTANA SCHOOL OF MINES  
BUTTE, MONTANA  
MAY, 1954



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BRECCIA OUTCROP (middle of picture). Obelisk of breccia formed by the outcrop of the breccia "pipe". It is this outcrop which suggested the name of the Obelisk Mine.



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Mr. Frank Soll of Basin, Montana, operator of the Obelisk Mine, for assistance in the field and for permission to write this report on the Obelisk Mine.



GEOLOGY OF A MINERALIZED BRECCIA "PIPE"  
NEAR  
BASIN, MONTANA

by James W. Allan

ABSTRACT

Located on the western flank of the Boulder batholith of southwestern Montana, the mineralized breccia "pipe" is opened by the Obelisk Mine. The intersection of two fault systems in the quartz monzonite of the Boulder batholith has provided the locus of the breccia "pipe". There is fairly conclusive evidence indicating that the present outcrop of the "pipe" lies only a few hundred feet below the former "roof" of the batholith.

A sulfide orebody, valuable chiefly for its silver content, occurs within the breccia "pipe". Galena and sphalerite are the most abundant sulfide minerals with lesser amounts of arsenopyrite, chalcopyrite, molybdenite, and an unidentified silver sulfide mineral. Gangue minerals are quartz, calcite, and rhodochrosite.

Hydrothermal alteration, mainly kaolinitization and chloritization, has strongly affected the breccia fragments. A progressive sequence of alteration from chloritization through carbonitization and finally kaolinitization was noted.

The breccia, in the writer's opinion, exhibits characteristics which are not readily explained by fault movement alone. Rather, there seems to have followed the initial faulting, a period during which the breccia was acted on by a strong hydrothermal current or "hot spring".



# GEOLOGY OF A MINERALIZED BRECCIA PIPE NEAR BASIN, MONTANA

## INTRODUCTION

### Purpose of Report

The writing of this report was undertaken to partially fulfill the requirements for the Bachelor of Science degree in Geological Engineering at the Montana State School of Mines. Faculty advisers for the investigation were Mr. W. S. March, Jr., and Mr. R. R. Reid, respectively Head of Department and Instructor in the Geology Department.

A study was made to determine the origin of a mineralized breccia "pipe" and to describe the sulfide ore-body which occurs in the "pipe". Investigations included the preparation of small-scale surface and underground maps of the breccia and the laboratory study of rocks and ores collected in the area. The geologic setting of the pipe is illustrated on a small-scale map showing the surface geology.

### Location and Physiography

The breccia "pipe", which is opened by the Obelisk Mine, is in the Basin mining district of southwestern Montana (see Fig. 1). Easily accessible throughout the year from either Butte or Helena, the main portal of the Obelisk Mine is located one mile east of the town of Basin and lies about 90 ft north of U. S. Highway 91.



Youthful stream valleys, dissecting a faulted and uplifted peneplane, form an early mature topography in the area. Local relief is moderate, the steep slopes of the valleys commonly reaching a height of about 800 ft above the valley floors (see Fig. 2).

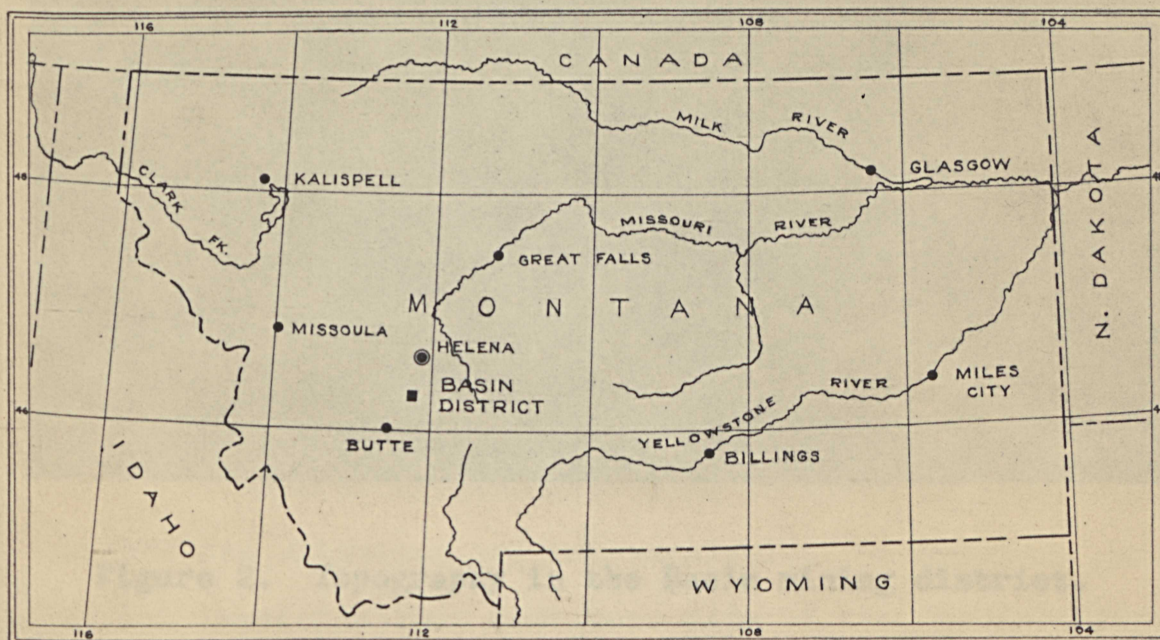


Figure 1. Index map of Montana showing the location of the Basin mining district.

The now dissected peneplane, developed in the rocks of the Boulder Batholith in the Eocene epoch (Billingsley and Grimes, 1917 - a)<sup>1</sup>, exposed large areas of granitic rock and has thus had an important influence on the present topog-

<sup>1</sup>Refers to references at end of paper.





Figure 2. Topography in the Basin mining district.

raphy. The most obvious of the effects of the peneplanation on present topography is the close conformance of the higher, flat-topped mountains to a tilted, rolling surface that was once the Eocene peneplane. Also, the present erosional forms of the area are being strongly influenced by the granitic character of the terrain. Features typical of this lithologic influence on land forms include, (1) large, rounded outcrops, (2) insequent, dendritic stream



patterns except where controlled by faults, and (3) the almost complete absence of any sheer cliffs or overhanging bluffs.

### History

Little information is available on the history of the Obelisk Mine. According to Mr. Frank Soll, present lessee of the mine, the orebody was first mined about 1880. The orebody, very closely controlled structurally by the breccia zone, is small and has yielded a relatively small amount of ore.

Mine operations are at present restricted to development work. One small shipment of approximately 5 tons of development ore was made in January, 1954.

Maps of inaccessible mine workings or records of earlier ore shipments are not available. No previous geological investigations have been made of the Obelisk Mine.



## AREAL GEOLOGY

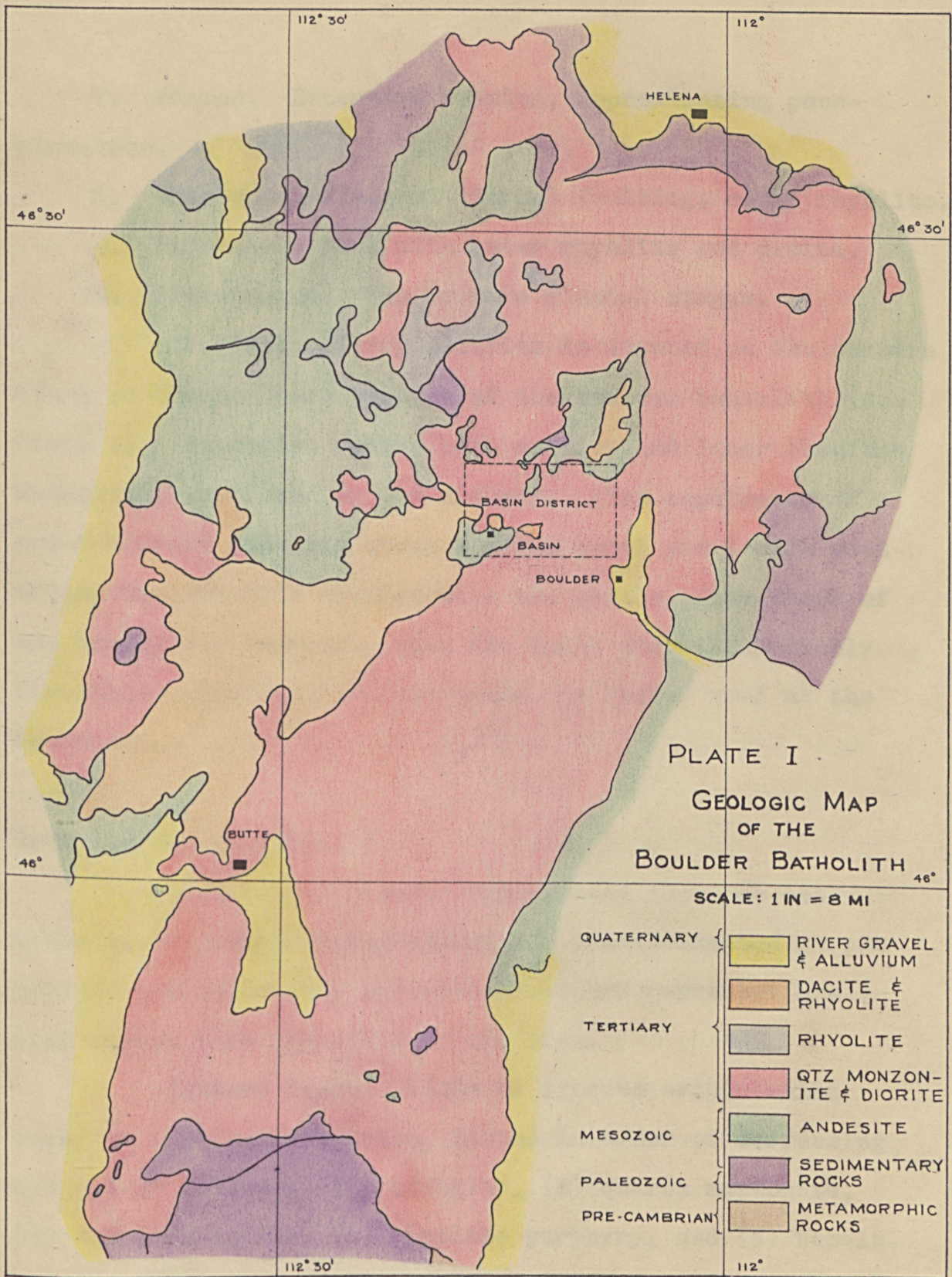
### Review of Geology of Boulder Batholith

The Boulder batholith, in which the mineralized breccia occurs and to which it is genetically related, is an intrusive body of granitic rock ranging from diorite to quartz monzonite in composition. Approximately 70 mi long and 40 mi wide, the batholith is elongate in plan with its long axis trending about N 30° E (see Plate 1). Detailed work by Billingsley (1915-a) has shown the batholith may have been intruded as a dome-shaped mass.

Located in the mountainous section of southwestern Montana, the Boulder batholith was intruded during the phase of the intense crustal deformation which formed the Cordillera of the Western United States. A chronological list of the events preceding and following the intrusion proposed by Billingsley and Grimes (1917-b) is summarized as follows:

1. Middle Cretaceous. Main Rocky Mountain folding.
2. Middle-Upper Cretaceous. Extensive erosion.
3. Upper Cretaceous. Andesite eruption.
4. Upper Cretaceous. Local intense erosion.
5. Upper Cretaceous. Thrust faulting along northwest trends.
6. Eocene (?). Intrusion of Boulder "Granite" Batholith.





(After Billingsley, 1915)



7. Eocene. Extensive erosion, approximating peneplanation.
8. Oligocene, Miocene. Normal faulting; early rhyolite.
9. Pliocene. Same with later rhyolite and dacite.
10. Pleistocene. Two or more glacial stages.

The Basin mining district is located on the western flank of the northern portion of the Boulder batholith (see Plate 1). Extrusive rocks, both earlier and later than the batholith, are found in the district. The occurrence of pre-batholith andesite about 2 miles north and 1 mile west of the Obelisk Mine coupled with the gentle, dome shape of the intrusive, indicates that the Basin district probably lies only a few hundred feet below the former roof of the batholith.

#### Rocks of the District

**Sedimentary Rocks.** Sedimentary rocks do not occur in the Basin mining district. Unconsolidated stream gravels and talus rock are widespread and represent the most recent rock aggregate of the area.

**Igneous Rocks.** Rocks of igneous origin which occur in the Basin district, listed in order of decreasing age are as follows: (1) andesite, (2) quartz monzonite, (3) alaskite-aplite, (4) rhyolite porphyry, and (5) basalt.

1. Andesite. Remnants of pre-batholith andesite flows occur in the northern and western parts of the



district (see Fig. 3). This rock was not found in the immediate vicinity of the Obelisk Mine.

2. Quartz monzonite. Quartz monzonite, the dominant rock type of the Boulder batholith, is by far the most abundant rock of the Basin district. Megascopically, the quartz monzonite is a medium grained, compact rock of pale green to gray color, speckled with biotite.

Examination of the quartz monzonite in thin section shows it to be composed of andesine ( $An_{42}$ ), perthitic orthoclase, quartz, biotite, hornblende, and the accessories magnetite, apatite, and zircon. Grain sizes average from about 3 to 5 mm in diameter with plagioclase usually forming the larger grains.

Alteration, probably deuteric, has formed some chlorite in the biotite and hornblende, and very minor sericite and clay mineral in the feldspars.

3. Alaskite-aplite. Aplite is an abundant rock in the northern part of the Basin mining district (see Fig. 3). The mode of occurrence of aplite in the vicinity of the mine is as narrow, steeply dipping dikes.

All gradations of alaskite to aplite are found, even in dikes of only a few inches thickness. Toward their centers, the dikes are often pegmatitic in texture and contain tourmaline. Although only a few minor occurrences of these rocks were found in the vicinity of the Obelisk



Mine, the breccia "pipe" itself contains considerable amounts of aplite and alaskite as fragments. No exposures of these rocks in place were seen underground.

Microscopic examination of the aplite shows it to contain quartz, perthitic orthoclase, microcline, and where pegmatitic, tourmaline. The aplite possesses a granophyric texture with an average grain size of about 1 mm. In the alaskite and pegmatite, the grains are considerably larger.

The intrusion<sup>1</sup> of the aplites probably followed very closely the consolidation of the batholith (Billingsley and Grimes, 1917-c).

4. Rhyolite porphyry. As exposed at the surface and in the adit level of the mine (see Plates III & V), the rhyolite porphyry occurs as an intrusive dike along a strong but barren east-west fault. Baking of the fault clay and gouge near the dike indicates the dike is post-fault in age; however, there is evidence of some movement along the fault since the intrusion of the dike (see Plate V).

In a hand specimen, the rhyolite is a gray porphyry with abundant phenocrysts of feldspar, quartz, and biotite. Many of the feldspar phenocrysts are completely

<sup>1</sup>In thin section, the quartz monzonite-aplite contact exhibits phenomena which indicate replacement. Grains of plagioclase and biotite occur in the aplite along its edges and granophyric intergrowths of quartz and orthoclase reach into the quartz monzonite. Thus, under the microscope, the contact is definitely gradational, and minerals of the quartz monzonite show no distortion or fracturing near the aplite.



altered to a clay mineral, probably kaolinite, and good pseudomorphs of this mineral after feldspar are common.

In thin section, the porphyry is seen to be composed dominantly of a microcrystalline ground mass with phenocrysts of quartz, sanidine, and biotite. The average phenocryst is about 1 mm in diameter with the larger feldspar and quartz phenocrysts having diameters of 4 to 5 mm. Quartz grains all show rounded outlines and are commonly poikilitic, enclosing biotite and sanidine.

Although no criteria for determining the relative age of the dike were found near the mine, Billingsley and Grimes, (1917-d) have shown similar rhyolite dikes to be post-vein in age (see Fig. 3).

5. Basalt. An intrusive plug of basalt in the quartz monzonite occurs about 200 ft north of the rhyolite dike. The plug is elliptical in shape with its long and short axes measuring respectively about 100 ft and 70 ft in length.

The basalt has diabasic texture with an average grain diameter of about 0.1 mm. It is composed of labradorite ( $An_{60}$ ), olivine, minor augite and accessory magnetite. As indicated by their strong undulatory extinction, the labradorite crystals have been distorted since their formation. Alteration of the olivine has produced a little antigorite.



That the basalt is intrusive into the quartz monzonite is indicated by the following: (1) alteration of the quartz monzonite around the plug; (2) generally finer grained texture of basalt near the contact, probably due to

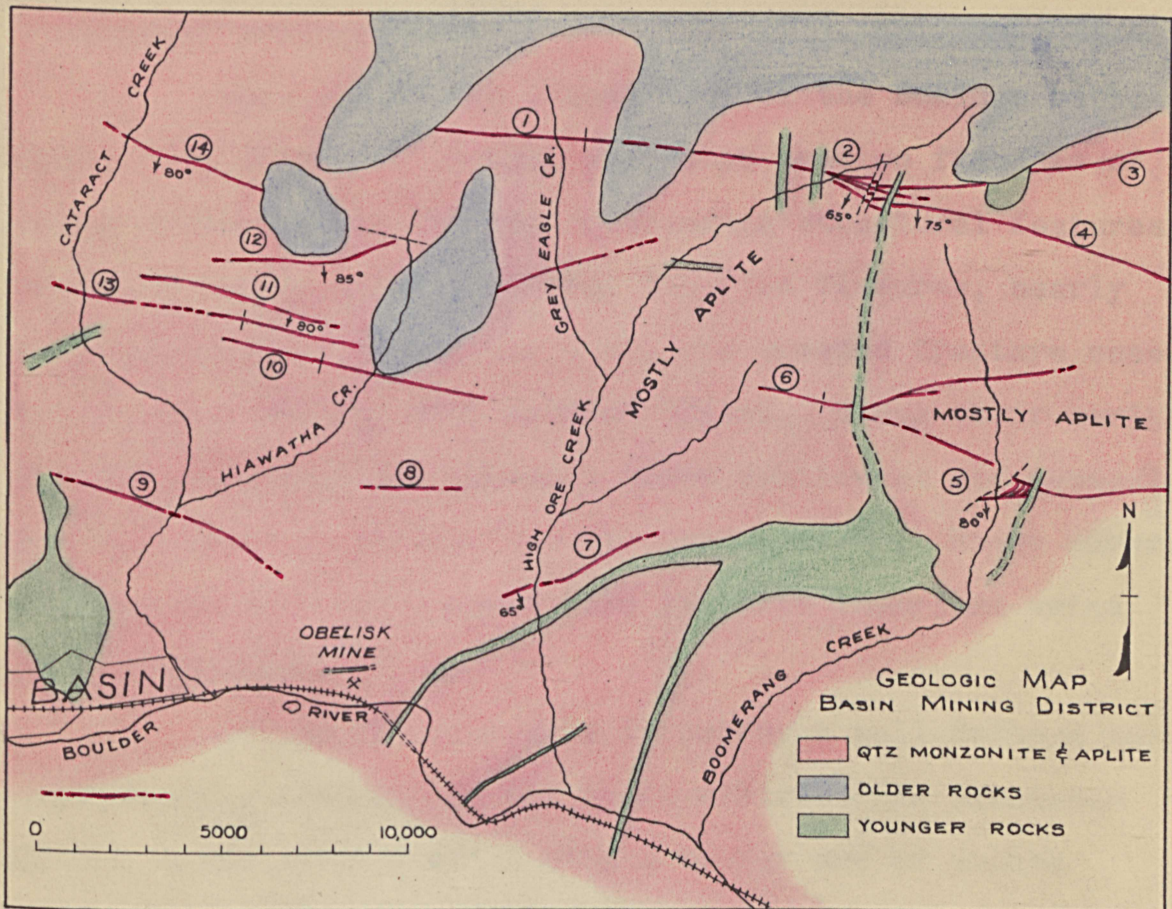


Figure 3. Geologic map of the Basin mining district (after Billingsley and Grimes, 1917). Veins: (1) Grey Eagle, (2) Comet, (3) Australian, (4) Rumley, (5) Baltimore, (6) Rochester, (7) Tom Paine, (8) Copper King, (9) Jack Smith, (10) Deerlodge, (11) Minneapolis, (12) Hiawatha, (13) Buckeye, (14) Saginaw.



chilling; and (3) parallelism of the jointing in the basalt with the contact. Billingsley and Grimes (1917-e) mention "rare occurrences of late diabase of Pliocene age" as marking "the last phase of igneous activity in the region".

### Structural Geology

Nearness to the former roof of the Boulder batholith and a system of strong, east-west tension fissures of steep southerly dip are the outstanding structural features of the Basin district (see Fig. 3). The fissures, nearly perpendicular to the former roof, are sheeted fracture zones rather than single, well-defined breaks. Along their strike, the fissure zones are commonly quite continuous and several may be traced on the surface for over 4 miles. Where mineralized, these fissure zones form the most important veins of the district.

The quartz monzonite is cut by a well-defined conjugate joint system. In the Basin district the strongest joints trend about N 45° E with a weaker set of joints trending at about right angles to them. In places a fairly strong east-west set of joints was noted.

Post-mineral rhyolite dikes traverse the district, radiating from a large mass of rhyolite about 3 miles northeast of the Obelisk Mine (see Fig. 3). A small, intrusive, basalt plug occurs about 600 ft north of the Obelisk Mine portal.



## GEOLOGY OF THE OBELISK MINE

### Geology of the Breccia

Relation to Other Ore Structures of the Basin District. The Obelisk Mine is located south of the main producing area of the district (see Fig. 3) and is the only known deposit of its type in the district. Although the valuable mineralization at the Obelisk Mine is localized



Figure 4. Outcrop of the mineralized breccia.



entirely within the breccia "pipe", it appears that the deposit was, in its early stages, a carbonate fissure vein similar to others in the district. This observation will be discussed in more detail below.

Like practically all other ore occurrences in the Basin district, the breccia orebody at the Obelisk Mine strikes east-west and dips steeply to the south (see Plate IVb). Further, the mineralogy and paragenesis of the ore minerals in the breccia are almost identical with those in other ore deposits in the district.

Size and Shape of the Breccia "Pipe". The breccia "pipe" forms, in plan, a wedge shaped prism which is at least 300 ft long along its strike and about 100 ft wide at its widest point exposed underground. The breccia body strikes east-west and plunges about  $80^{\circ}$  SW. In plan, the size and shape of the breccia zone exposed at the surface are similar to its size and shape on the adit level, 300 ft below. Although the shaft below the adit level is inaccessible, an oral description by Mr. Frank Soll of the stopes opened by the shaft, which is about 200 feet deep, seems to indicate that the breccia continues along the same plunge and does not change greatly in size or shape. The blunt, eastern end of the wedge is the locus of the ore, whereas the tapering western end of the wedge is barren of any sulfide mineralization.



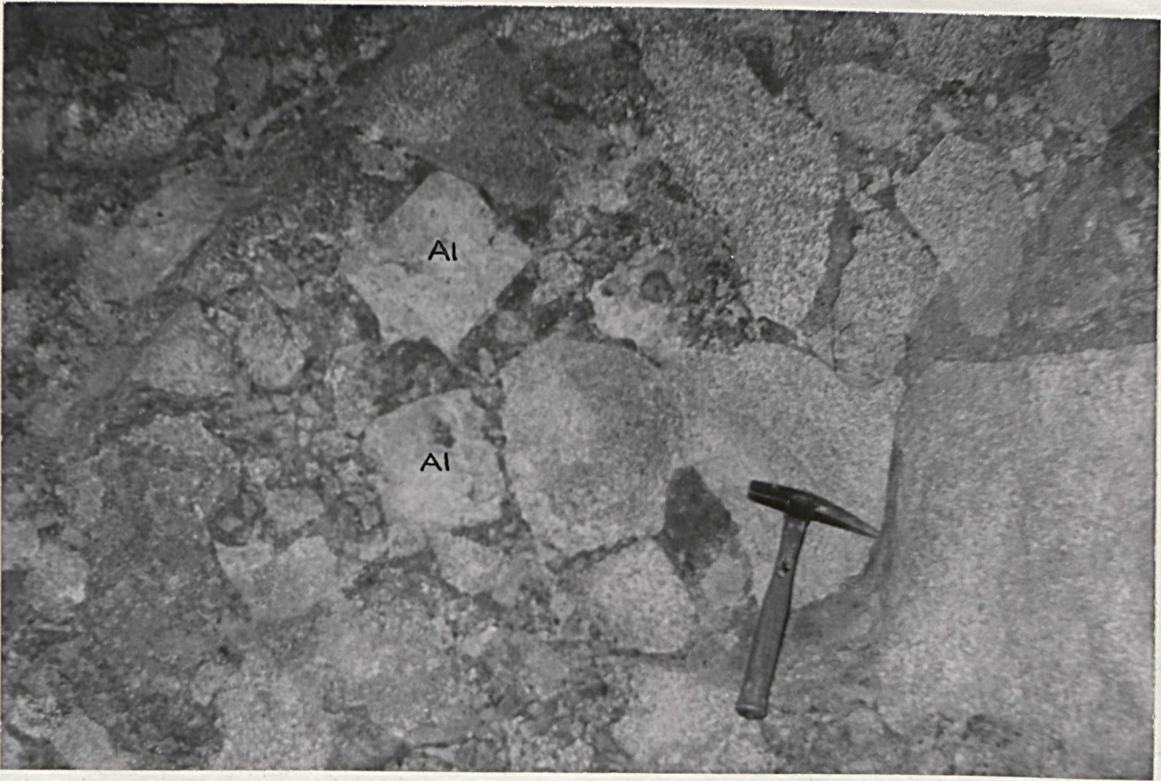
Texture of the Breccia. The breccia, which is entirely surrounded by quartz monzonite, is composed of highly altered fragments of quartz monzonite, alaskite, and aplite. Quartz monzonite fragments are the most abundant. Outside the limits of the breccia, no alaskite or aplite is exposed in the mine workings. Several fragments of carbonate vein material were found throughout the breccia.

Rock fragments in the breccia vary in size from microscopic in the matrix to several feet in diameter for the larger fragments. The average breccia fragment is about 6 to 10 inches in diameter. The scarcity of particles of an intermediate size is striking. Fragments of less than 2 or 3 inches in diameter are uncommon. The interstices of the larger fragments are filled by a comparatively well sorted matrix composed mainly of sand-sized grains of quartz and feldspar. In shape, the breccia fragments range from angular to well rounded. Generally speaking, the fragments nearest the breccia-quartz monzonite contact are angular whereas those toward the center of the breccia zone, especially in the oreshoot, exhibit differing degrees of roundness.

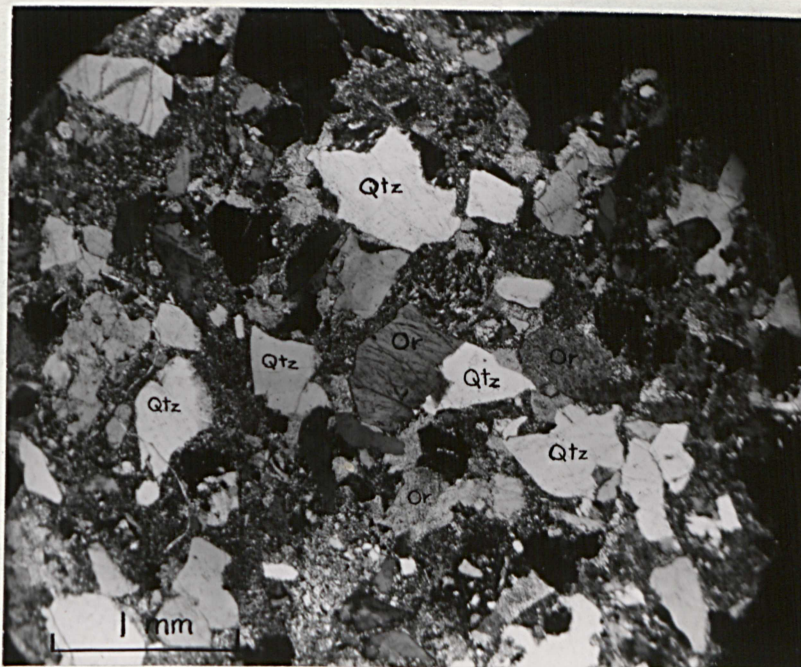
A study of the matrix in thin section reveals it to be a cataclastic mixture of quartz, orthoclase, microcline and a little biotite with the minor accessories apatite and zircon. Ranging from about 2 mm to submicroscopic in



PLATE II



A. Breccia as exposed underground.  
(Al-alaskite, remainder-qtz monzonite)



B. Photomicrograph of Breccia Matrix.  
(Qtz-quartz, Or-orthoclase)



size, the particles in the matrix are angular in shape. The average particle is about 0.3 mm in diameter. The cementing agents in the section studied were calcite and quartz. Alteration minerals are chlorite, muscovite, kaolinite, calcite and minor sericite.

As evidenced by their undulatory extinction and microscopic fractures, grains of quartz and orthoclase are strongly distorted. Cleavage planes of the biotite and muscovite are bent and warped. In the interstices of the larger fragments (2 mm), the rock minerals have been crushed and sheared until they now form a micro-breccia.

It is interesting to note the degree of sorting in the breccia matrix. In a hand specimen, the well-cemented matrix has the appearance of sandstone, a feature not commonly exhibited by subsurface breccias. Significant also, is the absence of hornblende and plagioclase and the scarcity of biotite in the breccia. These minerals are the most severely altered, which probably explains their scarcity in the matrix.

Because it is well cemented, the breccia is much more resistant to weathering than the surrounding, well-jointed quartz monzonite; a fact which is strikingly illustrated by the prominent spire which the breccia forms at its outcrop (see Fig. 4). Cementing materials include (1) quartz, (2) calcite, and (3) sulfide ore minerals.



- (1) Quartz, in places chalcedonic, is the principal cementing agent in the breccia. In places, pure quartz alone cements the larger breccia particles, elsewhere it is the cement of the fine-grained, cataclastic matrix of the breccia.
- (2) Calcite, less common than quartz, also occurs as a cementing agent in the breccia. Rare vugs are usually lined with calcite crystals.
- (3) Sulfide ore minerals cement the breccia in the ore zone.

It would appear that in the ore zone, silica is the principal cementing material; whereas, in the barren breccia the principal cementing agent is calcite. However, there were not sufficient exposures of the breccia to be certain. The resistant breccia spire, mentioned above, is at the apex of the oreshoot and is silica cemented.

Structural Features of the Breccia. On its southern and eastern boundaries where it is best exposed underground, the breccia is closely controlled by these two systems of faults, one striking east-west and the other a little west of north (see Plate V). The change from breccia to solid quartz monzonite at these places is abrupt; in each instance, one wall of the fault is breccia, whereas the other is solid quartz monzonite. Splits of these faults may be traced in places for a short distance into the breccia.



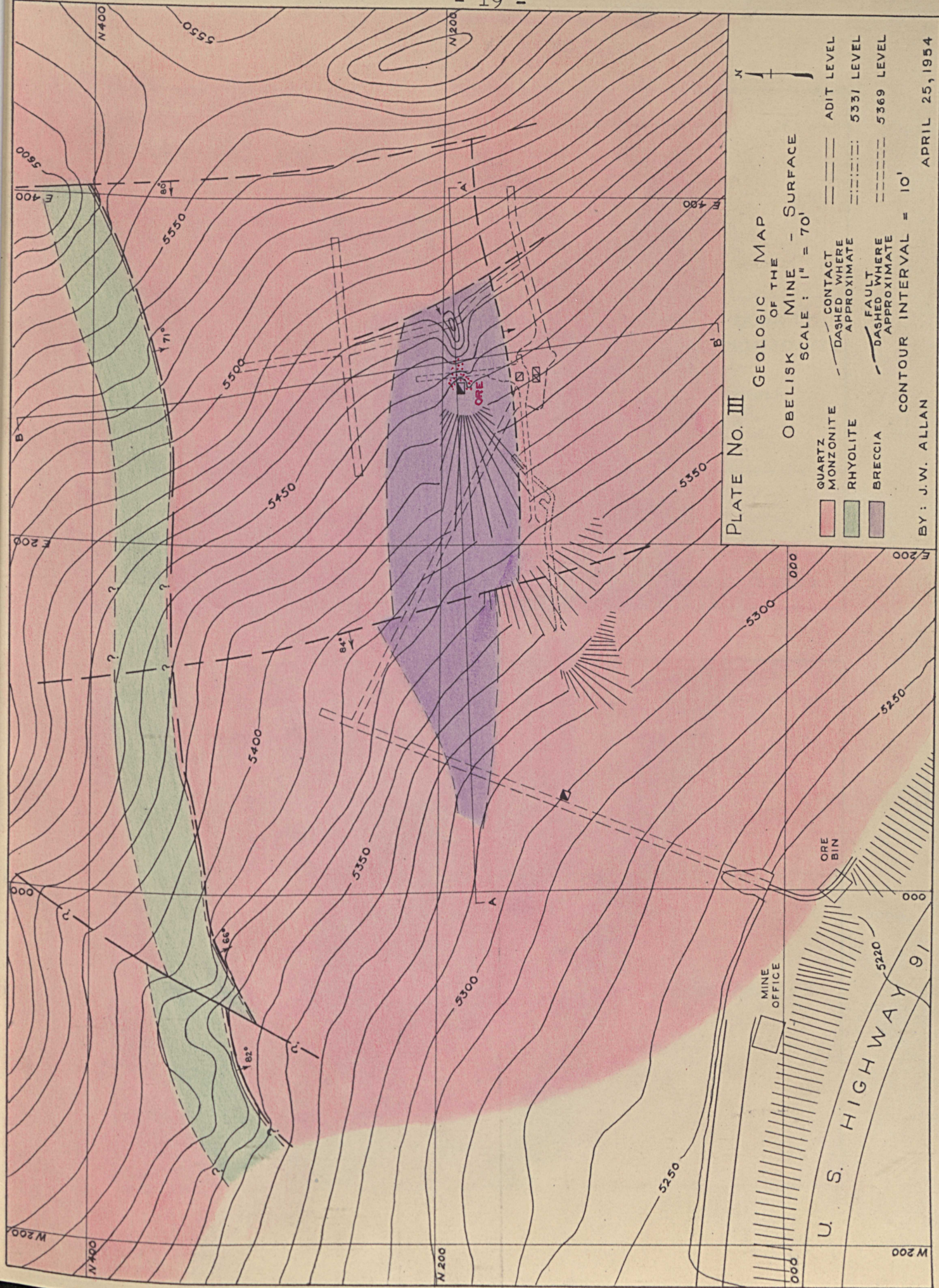


PLATE No. III

GEOLOGIC MAP  
OF THE  
OBELISK MINE - SURFACE  
SCALE: 1" = 70'

- |           |                          |            |
|-----------|--------------------------|------------|
| QUARTZ    | CONTACT                  | ADIT LEVEL |
| MONZONITE | DASHED WHERE APPROXIMATE | 5331 LEVEL |
| RHYOLITE  | FAULT                    | 5369 LEVEL |
| BRECCIA   | DASHED WHERE APPROXIMATE |            |

CONTOUR INTERVAL = 10'

BY: J.W. ALLAN

APRIL 25, 1954



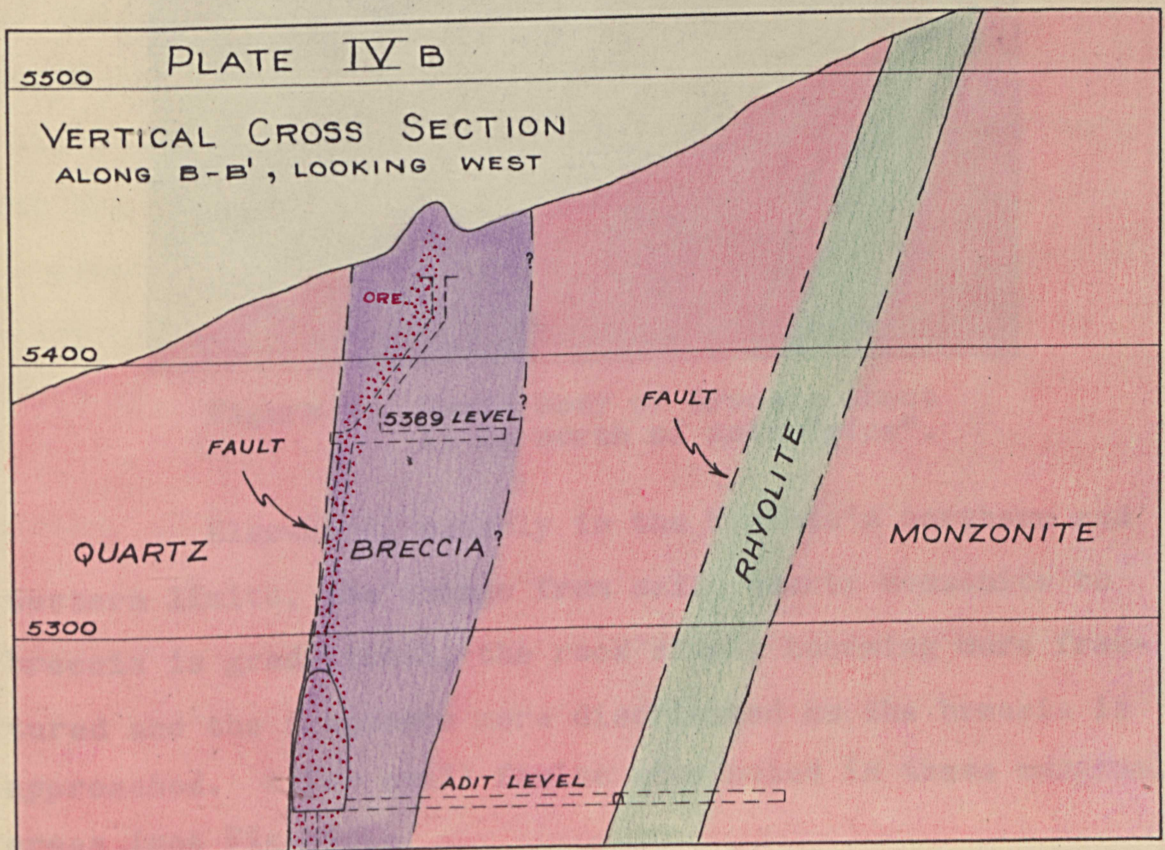
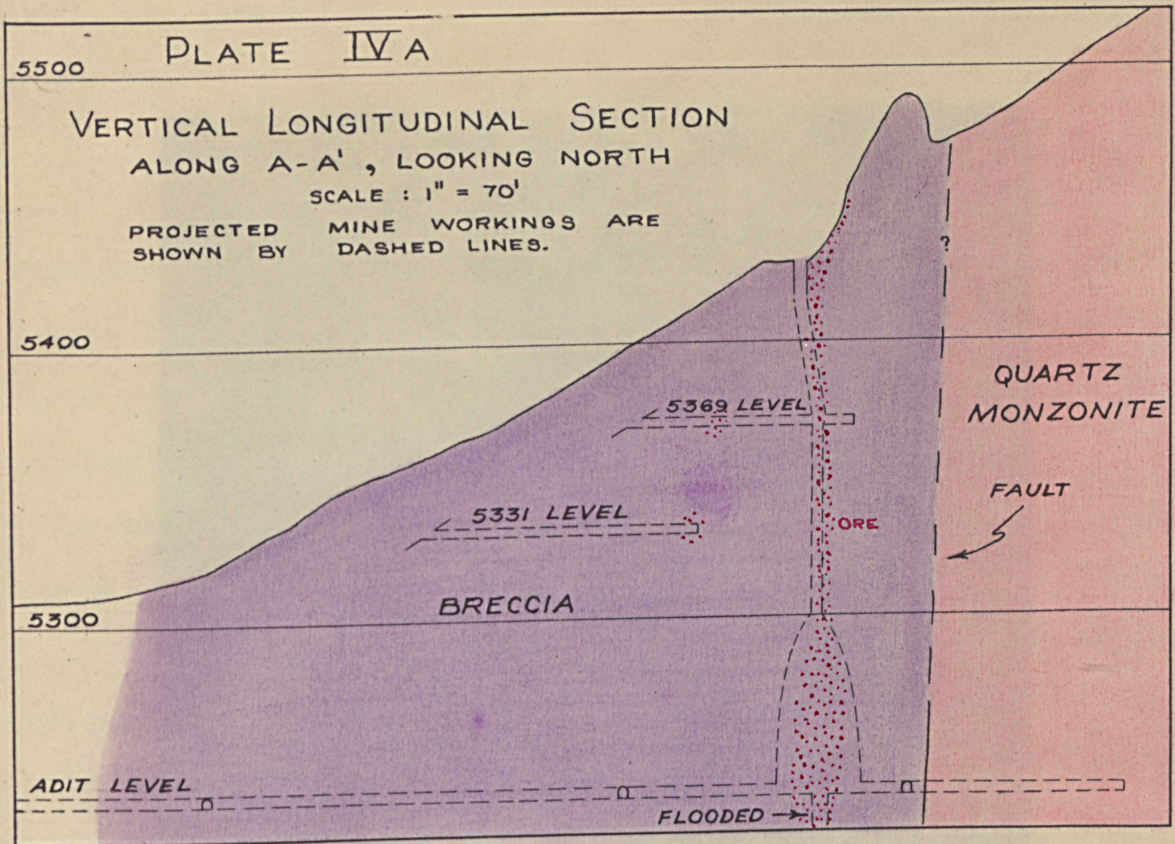






Figure 5. Small body of breccia about 15 ft north of main "pipe".

Elsewhere, notably in the breccia's northern and western limits, the change from solid quartz monzonite to breccia is gradational, the rock simply becoming more fractured and the fragments more disoriented as the breccia is approached. A few small faults were noted in these marginal areas (see Fig. 5).



The fault along the southern boundary of the breccia "pipe" grades in its eastern extremity into a fissure vein (see Plate V). The vein mineralization is a sequence of banded quartz, calcite, and rhodochrosite, with minor pyrite. Slickensides and brecciation in the vein material show that there has been post-mineral movement along the vein. Fragments of the vein material in the breccia indicate that the vein is pre-breccia in age.

Thus an intersection of two marked fault systems apparently provides the locus of the breccia "pipe". An early east-west system manifests itself in the strong fault along the footwall of the dike and along the southern flank of the breccia. The stronger east-west carbonate veins exposed underground also strike east-west. Faults of the later, less intense north-south system are exposed throughout the mine (see Plate V). Although some of the faulting is quasi-contemporaneous, the north-south faults almost everywhere cut and displace those striking east-west (see Plate V).

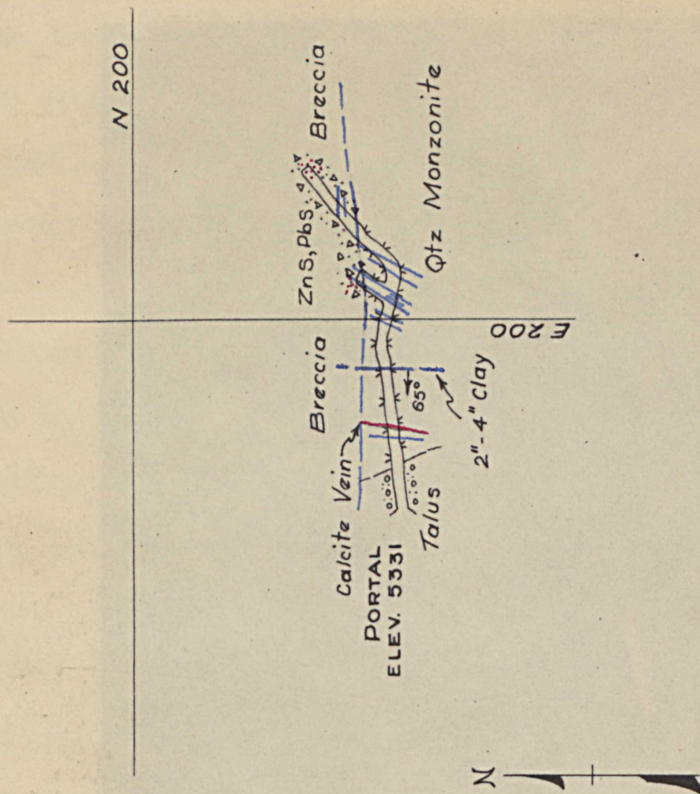
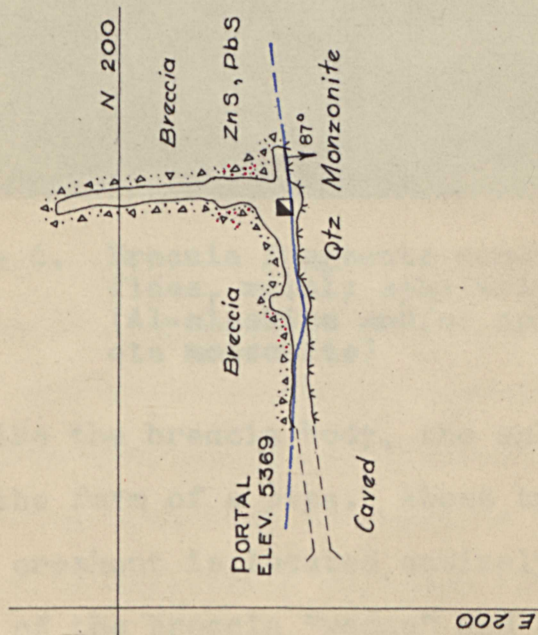
### Geology of the Oreshoot

Structure of the Oreshoot. The principal mode of occurrence of the sulfide ore minerals in the breccia is as a filling in the interstices of the rock fragments. Polished sections of the ore indicate that there has been only minor replacement of rock by sulfides.



PORTAL - ELEV. 5236





--- MINERALIZATION  
--- FAULT

# PLATE VI

GEOLOGIC MAP  
OF THE

OBELISK MINE - 5331 & 5369 LEVELS

SCALE: 1" = 50'

BY J.W. ALLAN

APRIL 15, 1954





Figure 6. Breccia fragments cemented with sulfides, mainly sphalerite and galena. (Al-alaskite and/or aplite, remainder-qtz monzonite)

Like the breccia body, the sulfide oreshoot is roughly in the form of a pipe. About twenty feet in diameter, the oreshoot is located entirely within the thick eastern end of the breccia "wedge" and forms an irregular spiral as it is traced along its nearly vertical course in



the breccia. The oreshoot is apparently not controlled by any post-breccia fractures. Rather, the mineral bearing solutions seem to have channeled their way through a more permeable zone in the breccia "pipe".

Mineralogy of the Ore. Ore minerals which occur at the Obelisk Mine, listed in order of decreasing abundance, are as follows: (1) sphalerite; (2) galena; (3) chalcopryite; (4) an unidentified sulfide or sulfo-salt of silver, and (5) molybdenite.

Sphalerite at the Obelisk Mine is mainly of the dark, iron-rich variety; however, small amounts of the purer, honey-yellow mineral are also present. The sphalerite occurs exclusively as a filling in the breccia. A few vugs lined with well-formed sphalerite crystals were found.

Galena occurs mainly as a replacement of sphalerite and possesses medium-grained cleavage. The cleavage planes of the galena are highly distorted and offset by minute fractures.

Chalcopyrite occurs sparingly and seems to be intimately related, both genetically and spatially, with the sphalerite. One polished section examined under the reflecting microscope, exhibits relations between sphalerite and chalcopyrite that seem to indicate exsolution; however, the chalcopyrite definitely replaces the sphalerite. Unimportant as an ore mineral, the chalcopyrite contributed only 0.05% Cu in the most recent assay of the ore.



The unidentified silver mineral, either a sulfide or a sulfo-salt, is at present the most important ore mineral at the mine. The ore is most valuable for its silver content of about 30 oz per ton. In every specimen so far observed, the silver mineral occurs mainly in the galena, apparently as a replacement.

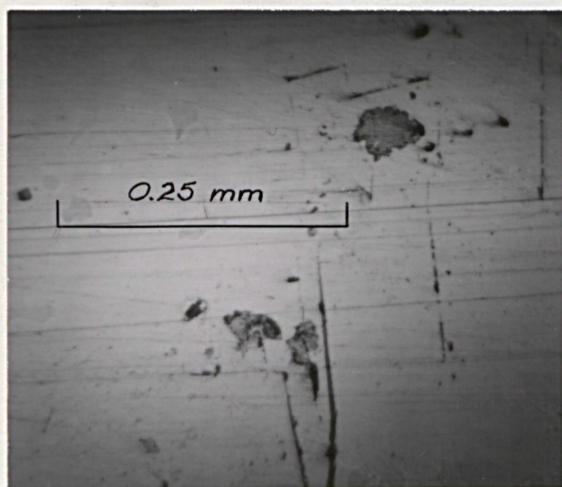


Figure 7

- (a) Photomicrograph of the silver mineral in galena. Vertical lines are cleavage traces in galena.
- (b) Same as (a), etched with 1 : 1 nitric acid.

The silver mineral occurs in the galena as minute blebs which are visible only under the microscope at high power (see Fig. 7). Etch reactions are as follows:



Nitric Acid.....negative  
Potassium Cyanide....quickly stains black  
Ferric Chloride.....negative  
Hydrochloric Acid....negative  
Potassium Hydroxide..negative  
Mercuric Chloride....stains very lightly

The mineral is soft having a hardness of from 2 to 3 on the Mohs scale and is grey when observed in polished section. It is apparently anisotropic and does not show internal reflection. Microchemical tests have established the presence of silver and antimony in the mineral.

Molybdenite is rare and of no economic importance; however, its value as a geologic thermometer is recognized.

Gangue minerals, also listed in order of decreasing abundance, are as follows: (1) quartz; (2) calcite; (3) pyrite; (4) rhodochrosite, and (5) arsenopyrite.

Quartz, which occurs both as vein mineral and in the breccia as a cementing material, is mostly chalcedonic. Some clear, vitreous quartz is found in the breccia; however, crystals of this mineral are rare.

Calcite, like quartz, is widespread and abundant. Practically all of the small veins and stringers around the breccia "pipe" are filled with calcite. Vugs containing well-formed crystals of calcite are abundant, especially in the faults outside the "pipe".



Pyrite is not abundant in the ores. Small pyritohedrons occur sparsely in the vein to the east of the breccia, in the altered wall rock of the "pipe", and in very minor amounts in the oreshoot. In view of the abundance of pyrite in other veins of the district, the scarcity of this mineral at the Obelisk Mine is puzzling. In all specimens of the ore studied, only two or three grains of pyrite were observed.

Rhodochrosite is found only in the above mentioned vein and as fragments of the vein in the breccia.

Arsenopyrite was seen in only one specimen, which was taken from the ore zone in the breccia. Like molybdenite, the arsenopyrite is significant mainly as an indicator of the temperature of formation of the ore deposit.

Mineral Paragenesis. Earliest of the minerals in the ore deposit are those of the east-west vein along which the breccia "pipe" was apparently formed. Of these minerals, quartz was the first deposited, its deposition continuing throughout the veins formation. Calcite, rhodochrosite, and pyrite followed in progressively smaller amounts.

A stage of strong brecciation separates the early period of barren mineralization from the later period of sulfide mineralization. In the study of a suite of ore minerals from the Jefferson Mine in the Basin district, I found that there, as at the Obelisk Mine, the deposition of the



early gangue minerals (see Fig. 8) was followed by a period of brecciation. The brecciation at the Obelisk Mine; however, was much more intense than elsewhere in the district. The brecciation, in all instances was obviously caused by recurrent movement along the fissures in which the veins were formed.

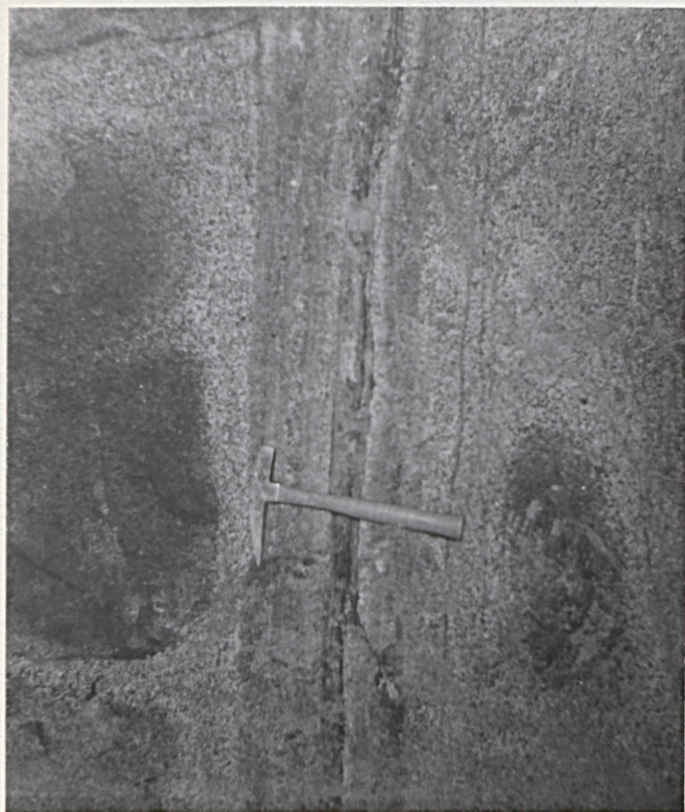


Figure 8. Early east-west quartz-carbonate vein. Note replacement of country rock and alteration.

Later sulfide mineralization, which occurred only in the breccia, was begun with the deposition, in very small amounts, of arsenopyrite and molybdenite. These minerals indicate an intermediate to high temperature of deposition (Bateman, 1952-a, Lindgren, 1933-a) in the earlier stages of "pipe" mineralization.

Following a lapse in mineralization, sphalerite and chalcopryrite were deposited. In at least one instance, the chalcopryrite appeared to be an exsolution product in the sphalerite; elsewhere the chalcopryrite was seen replacing



sphalerite. Their deposition was probably in part simultaneous; however, it appears that chalcopyrite continued to form after deposition of the sphalerite ceased.

A period of comparatively mild brecciation followed the deposition of the sphalerite. Galena then replaced sphalerite along microscopic fractures. In places the galena has completely replaced sphalerite, elsewhere it has only healed or slightly replaced the shattered sphalerite. It appears that the galena was deposited only as replacement of earlier sulfides, mainly sphalerite. Sphalerite, often in well-formed crystals, was the only sulfide seen lining vugs in the breccia. These vugs were almost certainly open during the period of galena deposition; however, not one contained that mineral.

Last and most valuable of sulfide mineralization in the "pipe" was the deposition of an unidentified silver sulfide mineral. Apparently a replacement, the mineral is revealed in polished section to occur as microscopic blebs along cleavage planes in the galena (see Fig. 7). The mineral appears to be concentrated in the galena near galena-sphalerite contacts. In at least one instance, a minute veinlet of the silver mineral leaves the galena and cuts across a residual fragment of sphalerite.

No minerals or textures indicative of supergene alteration were found. Even specimens taken near the surface



showed no effects of oxidation or supergene replacement.

Mineralization in the breccia "pipe" ended with the deposition of quartz and calcite. Quartz heals shattered sulfides and seams of calcite were noted in both the sulfides and quartz.

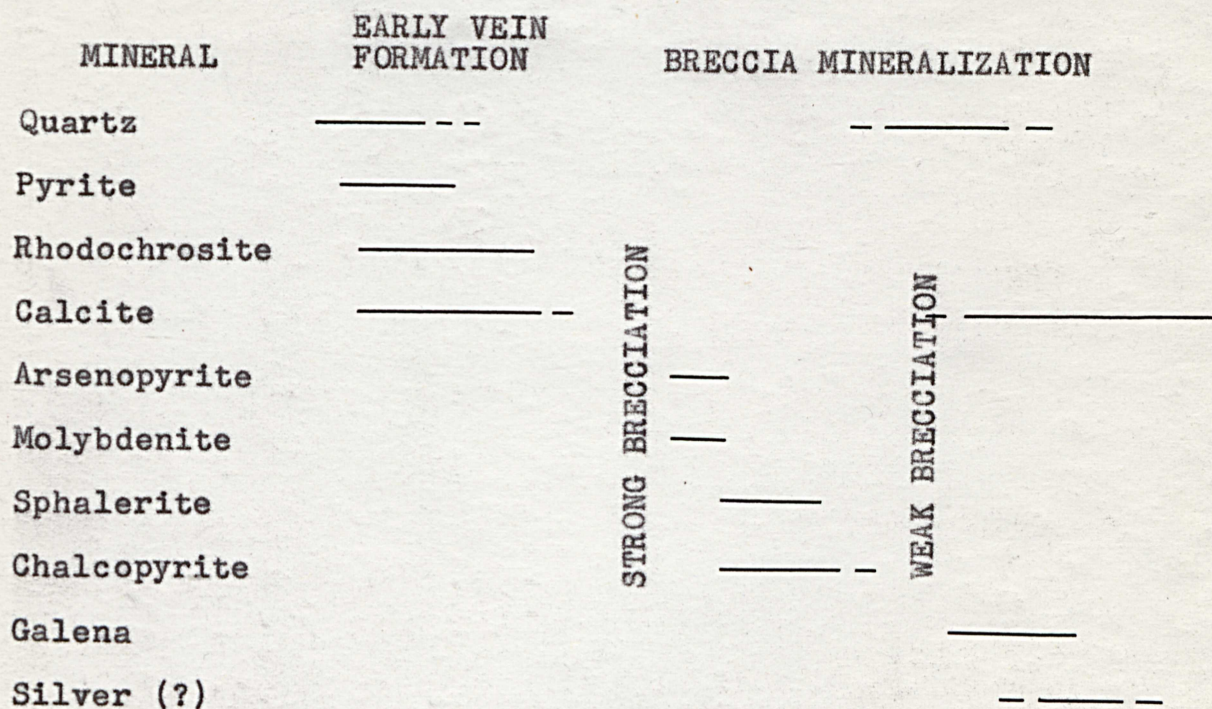


Figure 9. Paragenetic diagram, Obelisk Mine

Alteration. Hydrothermal alteration has strongly affected both the breccia in the "pipe" and the wall rock of the numerous carbonate veins and stringers outside the "pipe". Though apparently similar in type and intensity to that along the veins, the alteration in the breccia has been pervasive and all fragments so far observed have been completely altered.



The halos of alteration sheathing the carbonate veins are only a few inches thick except where the veins intersect and their alteration zones coalesce to form a greater volume of altered wall rock (see Fig. 10).

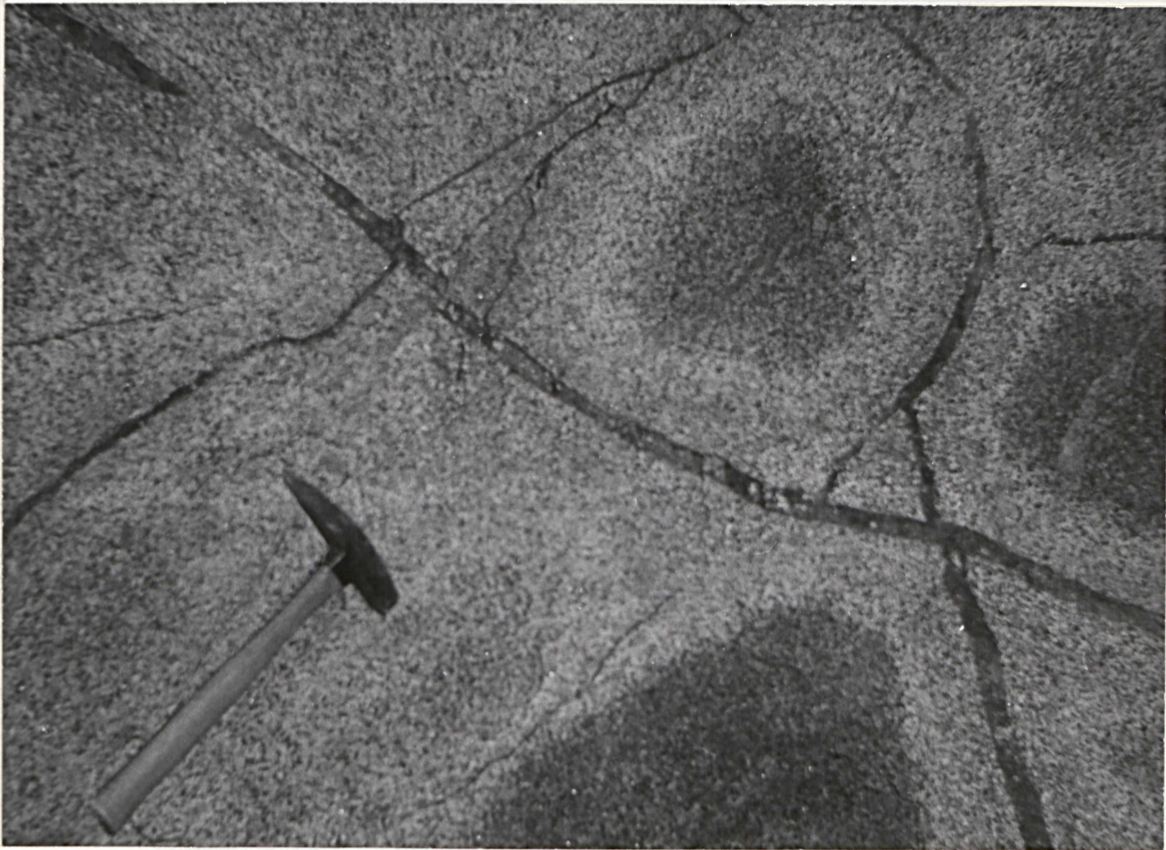


Figure 10. Alteration bands proceeding from small veinlets of calcite deposited in joints and cracks.

Alteration at the Obelisk Mine consists mainly of the formation of chlorite, kaolinite, silica, and calcite. Chlorite, silica, and calcite were identified in thin section



PLATE VII



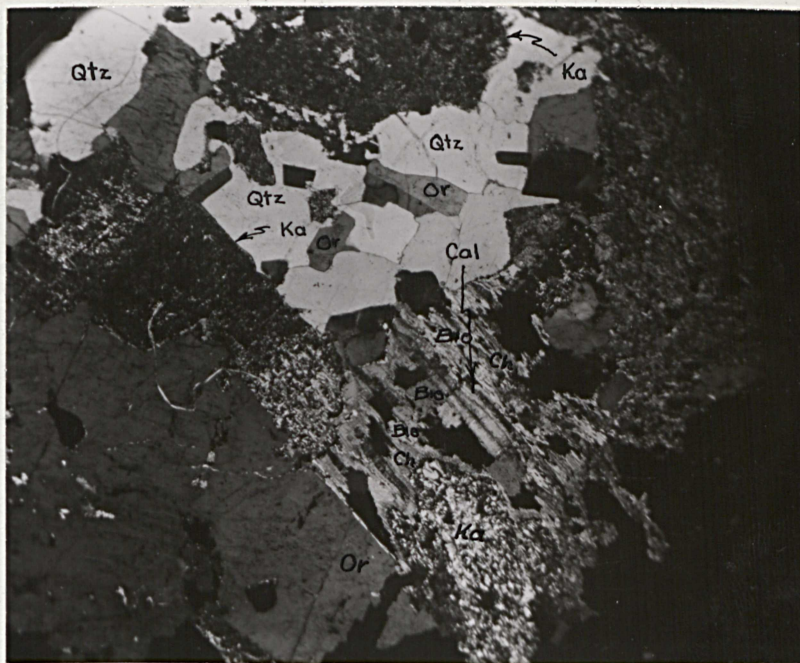
a



b



PLATE VII



c

- (a) Photomicrograph of "fresh" quartz monzonite. (Qtz-quartz; Bio-biotite; Ad-andesine; Or-orthoclase; Hbl-hornblende)
- (b) Photomicrograph of quartz monzonite in early stage of hydrothermal alteration. Same magnification as in (a). (Qtz-quartz; Bio-biotite; Ch-chlorite; Ad-andesine; Or-orthoclase; Hbl-hornblende; here mostly clay and calcite)
- (c) Photomicrograph of highly altered quartz monzonite. Same magnification as (a). (Qtz-quartz; Bio-biotite; Ch-chlorite; Or-orthoclase; Ka-kaolinite; Cal-calcite)



(see Plate VII). Kaolinite was identified through its x-ray diffraction pattern. Sericite, reportedly an abundant alteration mineral in the Basin district (Billingsley and Grimes 1917-f) is very scarce and did not show at all in the x-ray analysis of the clays.

Megascopically, the altered quartz monzonite has a bleached white appearance with progressively fewer black flakes of biotite as the mineralized channels are approached from fresh rock (see Fig. 10). A study of the alteration halos in thin section has roughly revealed the progressive changes which the ore-bearing solutions have superimposed upon the quartz monzonite wall-rock.

Plate VII-a is a photomicrograph of a specimen of unaltered quartz monzonite taken away from the mineralized zone. Alteration in this specimen is negligible.

The earliest effects of hydrothermal alteration of the quartz monzonite are shown in Plate VII-b. The specimen was taken from a residual boulder of fresh rock similar to those shown in Figure 10. Alteration effects on individual minerals are as follows:

- Plagioclase - Kaolinite and minor sericite are more strongly developed here than in the "fresh" rock.
- Orthoclase - Less intense kaolinite and sericite alteration.
- Biotite - Considerably altered to chlorite and penninite along basal cleavage planes. Pyrite has formed in a few of the biotite crystals.



Hornblende - Here the hornblende is almost completely altered to clay and calcite.

Thus in the early stages of alteration, the processes of chloritization and carbonitization have been most active. Argillation and pyritization have been much less intensive.

A specimen of highly altered quartz monzonite from the oreshoot is shown in thin section in Plate VII-c. Effects of alteration on individual minerals at this stage are as follows:

- Plagioclase - Completely altered to kaolinite.
- Orthoclase - A little more strongly altered to clay and sericite.
- Biotite - Almost completely replaced by chlorite and calcite along cleavage planes. The few remaining crystals of biotite are badly corroded and deformed.
- Hornblende - No hornblende was recognized in this thin section. It has apparently been completely altered to clay and calcite.

At this final state of alteration, argillation has become the dominant process. Chloritization has continued to be active and carbonitization has advanced to alter not only hornblende but also biotite. Silicification has made its appearance and is probably the final and most intense phase of alteration in the ore deposit.

Alteration of the breccia fragments probably took place prior to the sulfide mineralization. This is indicated by the similarity of the alteration around the early quartz-



carbonate veins (see Fig. 8 & 10) and that in the breccia "pipe". The breccia is altered throughout and alteration in the oreshoot appears to be similar to the alteration elsewhere in the "pipe".

Because erosion has so outstripped chemical weathering and due to the present impermeable nature of the breccia "pipe", oxidation of the ore is scarcely noticeable. Sphalerite, the most soluble of the sulfides, is found only slightly oxidized in the outcrop of the "pipe". The scarcity of pyrite in the oreshoot may also be an important factor in the shallowness of oxidation.



## CONCLUSIONS

### Origin of the Breccia

Breccia "pipes" in general have been attributed to several different phenomena including volcanic explosions, fault intersections, and the action of "hot springs". Although the possibility was considered that the breccia at the Obelisk Mine now occupies a volcanic explosion vent, no evidence supporting this mode of origin was seen.

The origin here proposed for the Obelisk breccia "pipe" is related to three geologic conditions. They are as follows: (1) a strong system of joints in the quartz monzonite; (2) the intersection of two steeply dipping fault systems; and (3) the later action of a strong, hydrothermal current on the fractured rock.

Although faulting and jointing in the quartz monzonite probably initiated the formation of the breccia, I do not believe these two conditions alone could result in a breccia like that exposed at the Obelisk Mine. Certain features now exhibited by the breccia which cannot, to me, be explained by fault movement alone are as follows:

1. The presence of considerable aplite and alaskite in the "pipe" in contrast to its absence in the quartz monzonite walls as exposed underground (see Plate II & Fig. 6).
2. The intense degree of alteration of the breccia wherever exposed.



3. The high degree of roundness of many of the breccia fragments, especially in the oreshoot (see Fig. 6).
4. The presence of a fine, compact matrix completely supporting much larger rock fragments in places (see Plate II & Fig. 5).
5. The presence of the same sandy matrix outside the "pipe" in discontinuous fractures along which there has seemingly been little or no movement (note fractures in Fig. 5).

It is here proposed that the above features were caused by active, hydrothermal currents or "hot springs" flowing upward through the breccia.

The presence of alaskite and aplite in the "pipe" would seem to indicate that the breccia fragments have moved either up or down the throat of the "pipe". It would indeed be an unusual coincidence if the aplite and alaskite fragments originally occurred only in the space now occupied by the "pipe" and did not extend into the quartz monzonite walls. That the breccia fragments moved down is logical. For a hydrothermal current to move such a mass of broken rock upward would require an unlikely volume of liquid flowing at a very unlikely velocity.

The only field indication that breccia fragments have moved downward is the occurrence of large bodies of aplite about  $1\frac{1}{2}$  miles north of the Obelisk Mine (see Fig. 3). Such flat-lying, aplitic bodies are commonly concentrated in a zone which is just below and roughly parallels the original roof of the Boulder batholith. As these aplite masses to the



north of the mine are at higher elevations than the "pipe" outcrop, they would, if projected southward with their present attitude, pass over the outcrop. Thus aplite bodies, now removed by erosion, could have provided the source of the aplite and alaskite fragments now seen in the breccia.

But broken rock is known to occupy more or at least as much space as the corresponding solid rock. It then becomes apparent that removal of considerable material was necessary to allow the breccia fragments to settle downward, if indeed they did. Hydrothermal solutions should be capable of removing this material, either as a turbid liquid or as a solution or more probably as both. As material was removed from below, ("mineralization stoping") the breccia fragments would tend to settle downward. The intense degree of alteration throughout the "pipe" is, to me, indisputable evidence that the breccia has been completely permeated by hydrothermal solutions.

The roundness of many of the fragments in the breccia may be attributed to alteration and to later attrition. Alteration bands, proceeding from faults, cracks, and joint systems could have started the fragments on their way to being rounded (see Fig. 5, 8 & 10). Later when they became part of the breccia, the fragments conceivably became more rounded as they sank slowly down the throat of the "pipe". Attrition would result from the churning, rolling action of the larger



blocks as they sank in the suspension of finer material.

Acting on particles previously liberated by the grinding action of fault movement and on particles then being liberated by attrition of the "suspended" rock fragments, hydrothermal currents could concentrate particles of different size ranges in different places within the pipe. This does not mean that there should be any significant change in particle size over a vertical range in the "pipe"; the currents would probably have been able to effect only local "sorting". The open fractures outside the "pipe" could have been "poured full" of the fine, clastic matrix by the currents.

As previously mentioned, ore deposition seems to have followed the pervasive alteration in the "pipe". There are no indications of any settling of the breccia since the sulfide minerals were deposited. This all points to the fact that the hydrothermal currents in the "pipe" were much less active during the period of ore deposition than they were in earlier stages of breccia formation. The oreshoot probably now occupies a channel which was kept open by the solutions in the later, less active stages of hydrothermal activity. This would explain the pipe-like form of the oreshoot within the breccia.

Results of thin section study of the breccia matrix are inconclusive in as far as determining the ultimate origin of the "pipe" is concerned. The matrix is a clastic mixture



of fine, angular rock fragments (see Plate IIb). In the interstices of these small fragments, the matrix in places appears to have been brecciated (microbrecciation) in the position it now occupies. This brecciation could be interpreted as an indication that the breccia matrix is a result of crushing and grinding alone in a fault zone. On the other hand, the brecciation could be taken to indicate crushing and grinding of the matrix since its "deposition" and partial consolidation by the hydrothermal solutions. There is a complete absence of any directional texture in the breccia matrix (see Plate IIb). Would there not be some directional shearing or foiliation of the less competent minerals if the breccia is to be attributed to fault movement alone?

To summarize, the proposed origin of the breccia "pipe", presented as a geologic history of the "pipe", is as follows:

1. Intrusion and solidification of the Boulder batholith with the development of a strong joint system.
2. East-west faulting, seemingly of a tensional type.
3. Mineralization of many of the east-west faults.
4. Weaker north-south faulting. Intersection of these two systems of faulting initiated the formation of the breccia "pipe" along an earlier east-west vein.
5. The flowage of a strong hydrothermal current up through the brecciated zone with its attendant alteration and "stoping" causing the breccia to slump or sink downward in the throat of the "pipe".
6. Ore deposition in a channel in the breccia during the final stages of hydrothermal activity.



### Problems Which Require Further Study

During the preparation of this report, several interesting problems were encountered on which little or no work was done. Certain of the problems were beyond the scope of this report; others will require more detailed research for their solution.

Those problems which seem to warrant mention are as follows:

1. The silver mineral should be identified.
2. The possibility of a recurrence of sulfide mineralization in the breccia to the west of the Obelisk Mine workings should be investigated.
3. The origin of the alaskite-aplite dikes and stringers in the district should be reinvestigated. The injection theory proposed for the origin of these rocks may be untenable in the light of replacement characteristics exhibited by the quartz monzonite-aplite contacts in thin section.
4. An attempt should be made to explain the scarcity of pyrite in the breccia oreshoot in contrast to its abundance elsewhere throughout the district. If it is true, as has been theorized, that pyrite in many ore deposits, obtained its iron from the alteration of ferromagnesian minerals in the wall rock, then a logical explanation is possible. The extended period of alteration by sulfur deficient solutions in the breccia could have removed most of the iron before the sulfur-laden, ore depositing solutions appeared in the "pipe".



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